7-12

AR 07-02

ACIDIC PRECIPITATION IN ONTARIO STUDY

ANNUAL PROGRAM REPORT
FISCAL YEAR 1982 - 1983

APIOS Report No. 001/84

Ontario

Ministry of the Environment

Hon. Andrew S. Brandt
Minister

Brock A. Smith
Deputy Minister

ACIDIC PRECIPITATION IN ONTARIO STUDY

ANNUAL PROGRAM REPORT

FISCAL YEAR 1982-1983

APIOS Report No. 001/84

Prepared by the A.P.I.O.S. Coordination Office
Ontario Ministry of the Environment
February, 1984

TABLE OF CONTENTS

Page

INTRODUCTION

The extensive environmental effects and the complicated control programs for acid rain fall under the jurisdictions of several Ministry Branches, several Provincial Ministries and both the Provincial and Federal Governments. As a result, a comprehensive project management structure has been put in place to ensure an efficient, results-oriented program. The value of this approach has been proven in that we have kept on top of the problem in the eyes of the public and that the high quality of our research is recognized worldwide. Our scientists act as advisors for at least four other countries. During the preparation of reports under the Canada/U.S. Memorandum of Intent, Ontario's research results largely established our case and our staff prepared a large portion of the reports.

Technical Committees: For each area of study (atmospheric, aquatic, terrestrial and analytical), a team of scientists from all relevant Branches and Ministries establishes the research needs and priorities.

Science Committee: Program supervisors from all appropriate Branches and Ministries ratify the research priorities and then allocate the available manpower and money to the program areas.

Acid Rain Committee: Branch Directors and senior Ministry staff from the Ministry of the Environment, the Ministry of Natural Resources and the Ministry of Intergovernmental Affairs establish overall policy and program directions and ratify the program resource allocation proposed by the Science Committee.

Coordination Office: This Office provides overall leadership and conducts the budget preparation and management during the year for the program. The Office provides secretarial support to the above Committees, prepares quarterly reports, program overviews and annual reports. Policy options are usually developed by the Coordination Office for consideration by the Acid Rain Committee.

In addition to its internal structure, Ontario co-chairs a Federal/Provincial Steering Committee dealing with Canadian policy and a Federal/Provincial Research and Monitoring Coordinating Committee which coordinates the research efforts of the federal and eastern provincial governments. The Federal Government has a Coordination Office similar to Ontario's and the Coordinators keep in close touch on all relevant activities and issues.

PROGRAM OBJECTIVES

General

To develop a strategy to protect the Ontario environment based on the study findings.

Specific

1. To determine the effects of atmospheric deposition on aquatic ecosystems including: water quality, phytoplankton, zooplankton and fish communities.

2. To determine the atmospheric transport and deposition of acids and acid forming materials, metals and other relevant constituents for Ontario.

3. a) To investigate the feasibility of developing cost effective interim mitigative programs to preserve affected aquatic ecosystems.

   b) To investigate the feasibility of developing cost effective interim mitigative programs to rehabilitate affected aquatic ecosystems.

4. To determine the effects of atmospheric deposition on terrestrial ecosystems including soil biogeochemistry and vegetative regimes.

5. a) To investigate the feasibility of developing cost effective interim mitigative programs to preserve affected terrestrial ecosystems.

   b) To investigate the feasibility of developing cost effective interim mitigative programs to rehabilitate affected terrestrial ecosystems.

6. To investigate the socio-economic benefits of alternative air pollution abatement strategies.

7. To investigate the human health effects of the acidic precipitation phenomenon.

TASK #1 - ATMOSPHERIC PROCESSES STUDIES

A. Emissions Inventory

Past efforts in this area have resulted in a current acidic precipitation emissions inventory with good data for significant sulphur dioxide emitters (in excess of 100 tons per day) for eastern North America. This inventory is already being used in the long range transport models presently being developed. These models depend on accurate up-to-date emissions data for their ultimate application in regulating emissions.

A complete inventory of major 1980 SO_2 emissions from the US and Canada was completed in FY 82/83. Emission information from the National Emission Data System of the American Environmental Protection Agency, data from U.S. power plants, major Ontario sources, and updated information from the Canadian Environmental Protection Service were combined to create the 1980 Acid Rain Master Data File. A summary of the SO_2 emissions is presented in Table I.

In combination, the 1980 Acid Rain Master Data file was created. This includes emissions data for all of North America, broken down by individual plant and stack (See Table I for a summary).

Contracts for an Ontario area source emission inventory for nitrogen oxides, and for a preliminary study for the completion of a volatile organic carbon emission inventory for Ontario were completed.

B. Modelling and Meteorology Studies

i) Atmospheric Modelling

Mathematical models have important roles to play in APIOS. The first is as a yardstick for our understanding of the acidic deposition phenomenon. By combining our knowledge of the movement of air masses and the chemical transformation of pollutants during transport into a model, the output of the model can be compared to observed deposition patterns. If the comparison shows a close agreement, we gain confidence that we have a good understanding of the causes and mechanisms involved in acid deposition. Another role is as a tool for the evaluation of abatement strategies. Once the models are sufficiently developed, emission reduction scenarios can be assessed by looking at resulting deposition patterns.

There are currently two MOE models of long range transport of atmospheric pollutants. The Statistical model computes long term average pollution concentration and deposition, based on statistics of meteorological variables over many years. The Lagrangian model uses time-varying meteorological observations to compute the trajectories of puffs of pollutant, whose effects are summed over a

TABLE I

SUMMARY OF 1980 ACTUAL SO_x AND NO_x EMISSION DATA FOR NORTH AMERICA
(all data in thousands of tonnes)

1. SO_x Emissions	Electric Utilities	Non Ferrous Smelters	Other	Total
Canada	653 (4%)	2,177 (52%)	1,886 (19%)	4,656 (15%)
U.S.	15,535 (96%)	1,938 (48%)	7,822 (81%)	25,295 (85%)
Total	16,188 (100%)	4,015 (100%)	9,708 (100%)	29,951 (100%)

2. NO_x Emissions	Electric Utilities	Non Ferrous Smelters	Other	Total
Canada	230 (4%)	0 (0%)	1,581 (10%)	1,811 (8%)
U.S	5,581 (96%)	108 (100%)	15,083 (90%)	20,771 (92%)
Total	5,811 (100%)	108 (100%)	16,664 (100%)	22,582 (100%)

specified period of time, such as a year or a season, to yield time-averaged pollutant concentration and deposition.

The Lagrangian model has been employed to simulate annual average concentrations of SO_2 and $SO_4^=$ and wet deposition of total sulphur for the year 1979 over eastern North America. The calculated concentration and deposition values compared favorably with values from the monitoring networks. Seasonal trends, dependent on seasonal variation of meteorological conditions, have also been calculated for 1979. In general, the highest $SO_4^=$ concentrations are measured in summer, with SO_2 concentrations reaching their peak in winter. Wet sulphur deposition is generally low in winter. For the rest of the year, seasonal trends vary geographically depending on rainfall distribution and wind patterns.

With improved meteorological data for the years 1978, 1979 and 1980, trajectories have been initiated at three hour intervals from 60 source locations over an area extending from the Rocky Mountains to the east coast, some 500,000 trajectories in all. Statistics of these trajectories are being prepared for use in the MOE Statistical model. Concentrations and deposition of SO_2 and $SO_4^=$ as annual and seasonal averages are also being computed. The trajectories are stored on magnetic tape and are available for simulation of the transport of other pollutants when emission inventories and their atmospheric chemical processes are sufficiently well known. Future work will include the ongoing calculation of trajectories and associated concentrations and deposition of sulphur for the years 1981, 1982 and further years as data become available. This makes possible the evaluation of long term average annual and seasonal values and their year-to-year variations.

Annual average $SO_4^=$ concentrations computed by the Lagrangian model based on calculated wind fields and precipitation for 1979, are shown in Figure 1. The highest calculated concentrations, greater than 8 $ug \cdot m^{-3}$ occur in three locations. These are: a) the source area in Ohio extending into Pennsylvania, West Virginia and southern Ontario, b) the source area in Illinois and c) at Sudbury, Ontario. Figure 2 shows wet deposition of total sulphur in kg $ha^{-1} \cdot yr^{-1}$, simulated by the Lagrangian model for 1979. Total wet sulphur deposition computed as a long term annual average by the Statistical model, in $g \cdot m^{-2} \cdot yr^{-1}$, is shown in Figure 3. Multiplication by 10 converts $g \cdot m^{-2} \cdot yr^{-1}$ to $kg \cdot ha^{-1} \cdot yr^{-1}$. Both the Lagrangian and Statistical models predict maximum values of wet sulphur deposition for the source regions in the Ohio valley and near Sudbury. The models also simulate high values extending eastward through Pennsylvania. The effects of the west to east flow used in the Statistical model are apparent in the eastward extension of the isopleths in Figure 3. Use of the observed wind pattern in the Lagrangian model

simulation creates the northward bulge of the maximum isopleth into southern Ontario, carried on southwesterly winds from the source areas in the Ohio valley.

It is interesting to compare the wet deposition simulated by the Lagrangian model (Fig. 2) with annual wet deposition measured by the APIOS network (Fig. 4) although it should be noted the time periods do not overlap. The isopleths in Figure 2, whose values, in $kg \cdot ha^{-1} \cdot yr^{-1}$ of sulphur, when multiplied by 3/10 to convert them to $g \cdot m^{-2} \cdot yr^{-1}$ of sulphate, become 1.2, 2.4 and 3.6. A comparison with Figure 4 shows very good agreement.

In FY 82/83, a sulphur dioxide emissions inventory, for the use of the Memorandum of Intent Work Group 2, was developed, with contributions from MOE scientists. Model evaluation carried out by Work Group 2 showed the MOE Statistical model estimates to be as accurate, or better, than the wet deposition estimated from the other participating models.

Work was started on the development of a mesoscale air quality and pollutant deposition model. The mesoscale model should provide information on a smaller geographic scale than the Statistical Model.

In September of 1982, a peer review was carried out on the Regulatory, or Eulerian model developed during Phase I, and it was the unanimous opinion of the scientists on the review panel that work on the model should continue. Thus, Phase II was commenced, with the joint sponsorship of MOE, the Atmospheric Environment Service, and the Federal Republic of Germany. The Eulerian Model is more complex than the Statistical and Lagrangian models, and includes a state-of-the-art treatment of advection, homogeneous and heterogeneous chemistry, dry deposition, cloud physics and wet deposition. It will predict ozone levels as well as acidic deposition, and will be most useful in planning sulphur, nitrogen and hydrocarbon control strategies.

ii) Meteorological Data Acquisition System

Now complete is the trajectory analysis of 18 months of precipitation data collected at locations in southwestern, central and eastern Ontario, which relates the wet deposition of various chemical species to octant of airmass origin.

The results for several chemical species and for different trajectory lengths were determined. Despite some sources of error relating both to the data itself and to the analysis procedure, we can conclude that southerly to westerly airflows are associated with at least 50% of the wet deposition of sulphate and nitrate. The loading contributions vary somewhat according to location and according to length of trajectory (in hours). Mean event loadings are also highest for airflows between south and west.

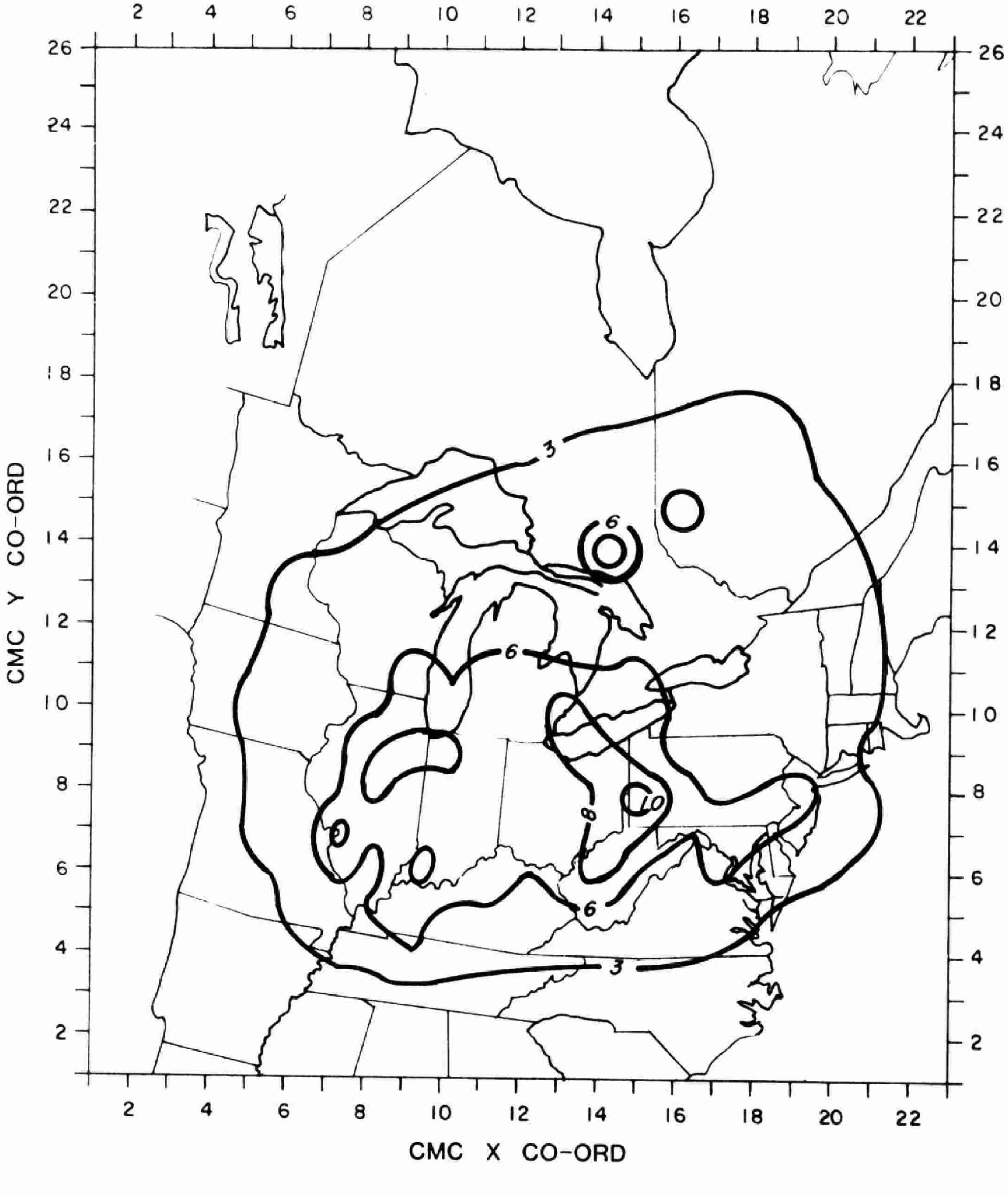

Figure 1: **Model Computed Annual Average SO_4 Concentration for 1979 in $\mu g\ m^{-3}$, Including Background of $2 \mu g\ m^{-3}$**

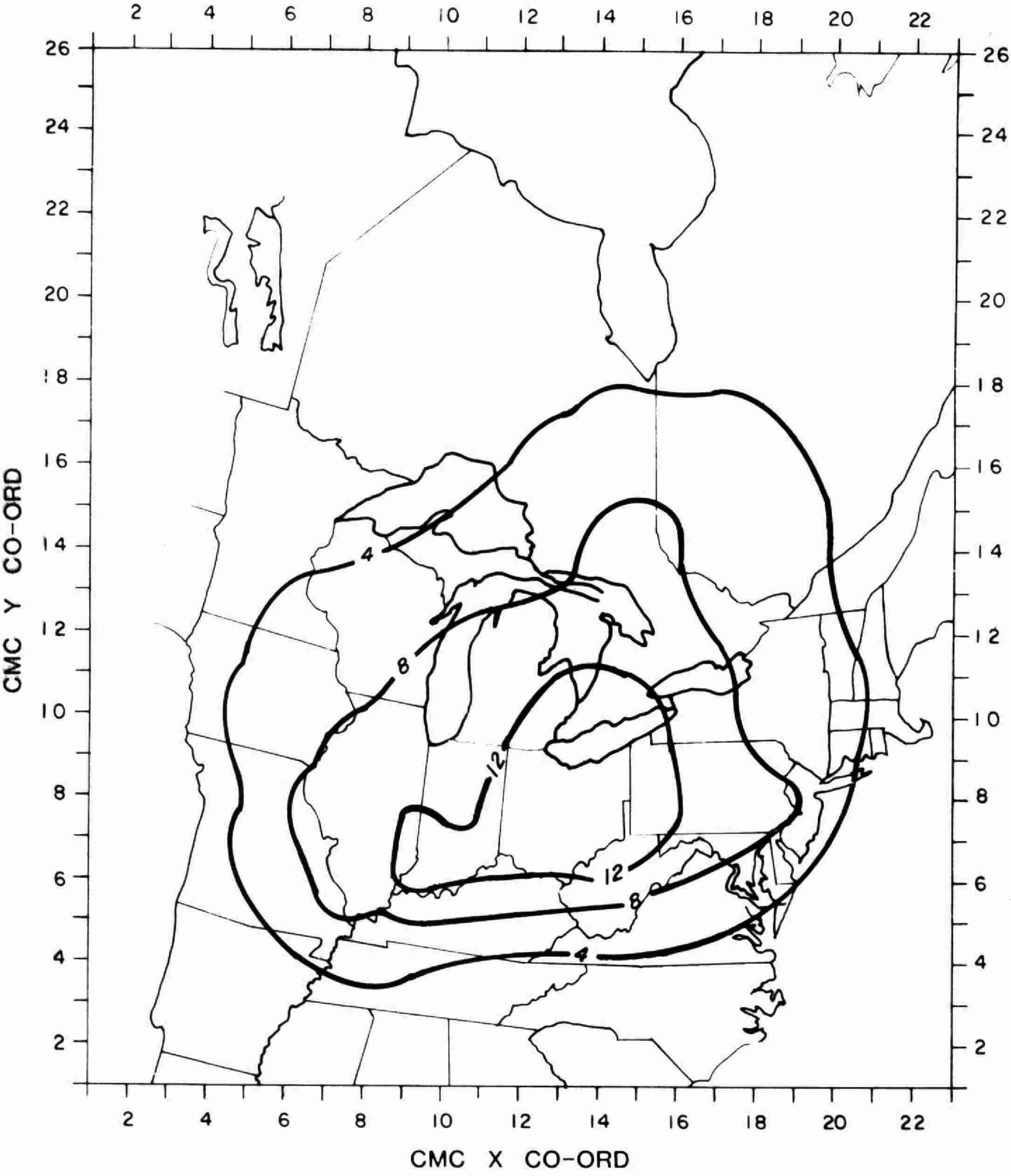

Figure 2: **Model Computed Annual Accumulation, wet Deposition of Total Sulphur in kg ha^{-1} yr^{-1}, Including Background of 2 kg $ha^{-1}$$yr^{-1}$**

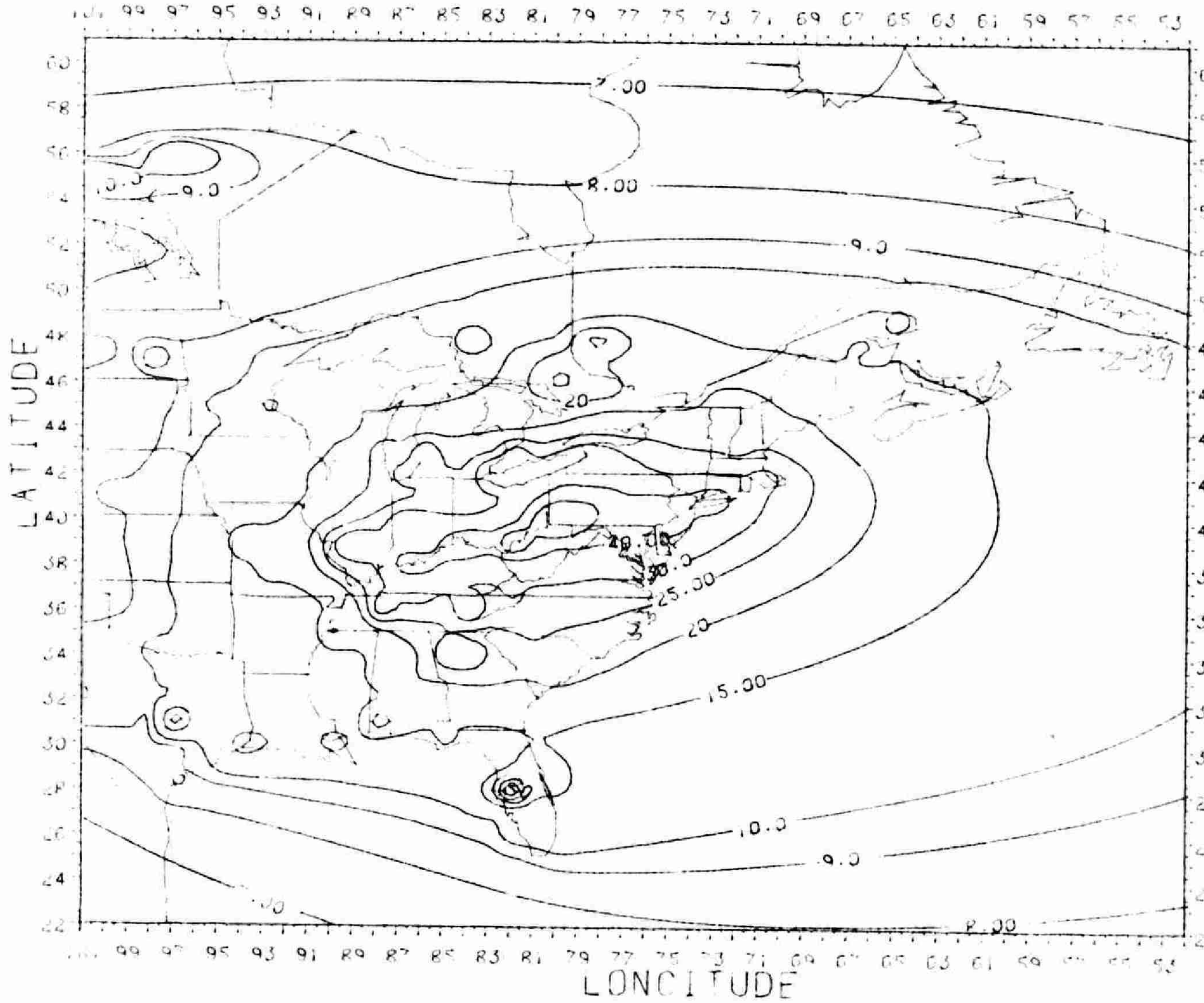

Figure 3: Absolute S Deposition of Wet Sulphur (in Kg SO_4/Ha/Yr) U.S. and Canadian 1980 Emission Inventory

Contribution from Other Sources is 6.0

Southwesterly air reaching southern and central Ontario has passed over the industrialized Ohio Valley which is heavy in sulphur and nitrogen oxide emissions. Such air is generally associated with more precipitation than air from other directions for synoptic meteorological reasons, and this only exacerbates the wet deposition problem for Ontario.

The trajectory analysis work is continuing and the statistics are continually being updated. Analysis of data collected at event precipitation sites in northwestern Ontario will be included in the next phase.

C. Deposition Monitoring Networks

During FY 82/83, the emphasis of the APIOS deposition monitoring program was to consolidate the networks and to report data obtained from the program.

Network consolidation included development and improvement of instrumentation, replacement of some unsuitable sites and the implementation of a quality assurance program. A quality assurance audit of network, database and laboratory operations has been carried out by an independent group (Concord Scientific Corporation) - to our knowledge, the first such audit of a deposition monitoring program in North America. The auditor's report was generally favourable, and his recommendations are being currently implemented.

At present, the cumulative network collects precipitation on a 28 day basis. Dryfall samples are collected at 36 sites, as well as low volume filter samples at 23 sites. The event network collects daily precipitation samples at 16 sites and daily low volume filter samples at 4 sites in the province. The density of the cumulative network is greater in the south of the province. The event network includes four clusters at the Dorset, Kingston, London and Atikokan areas.

During FY 82/83 data listing reports were prepared for the event and cumulative precipitation networks, and the lo-vol air sampling networks obtained from the inception of the networks to the end of 1981. Analyses of the event and cumulative network data have also been carried out, dealing with the sector of origin of the observed deposition in the event stations, and the deposition patterns in Ontario. Both types of analysis demonstrate the importance of long range transport from the south to the monitoring sites in Ontario. Of particular interest is the sulphate deposition map which indicated that the sulphate loading of 20 $kg \cdot ha^{-1} \cdot yr^{-1}$, which is considered as being critical for sensitive water bodies, is exceeded in all of southern Ontario (see Figure 4). Figure 5 shows hydrogen ion concentrations, and precipitation pH values, observed in the province in 1981.

A considerable amount of time was spent in reporting the data analyses and conclusions from the Sudbury Environmental Study, and a number of scientific presentations were given, and papers published. Also, MOE scientists participated extensively in the Memorandum of Intent Work Group 2 activities related to monitoring and data interpretation, and were involved in a number of joint projects including a cloud chemistry study (with the Atmospheric Environment Service), the planning of a regional - scale tracer experiment, CAPTEX, with several American agencies and intercomparisons and evaluations of wet and dry deposition monitoring equipment.

D. Laboratory Support

Laboratory support for the Deposition Monitoring Program amounted to 69,685 analyses. Significant improvements in several analytical techniques resulted in reduced sample backlogs compared to the previous year. These included an improved acidity test that doubled the Laboratory's capacity, and the routine analysis of several metals by a new direct coupled plasma spectrometer. Work continued on the use of X-ray fluorescence for metals in precipitation, and the development of suitable preservation and analytical methods for mercury.

The Laboratory also participated in a number of studies designed to detect sample contamination sources, and developed quality assurance procedures to ensure data comparability between the Dorset and Rexdale laboratories.

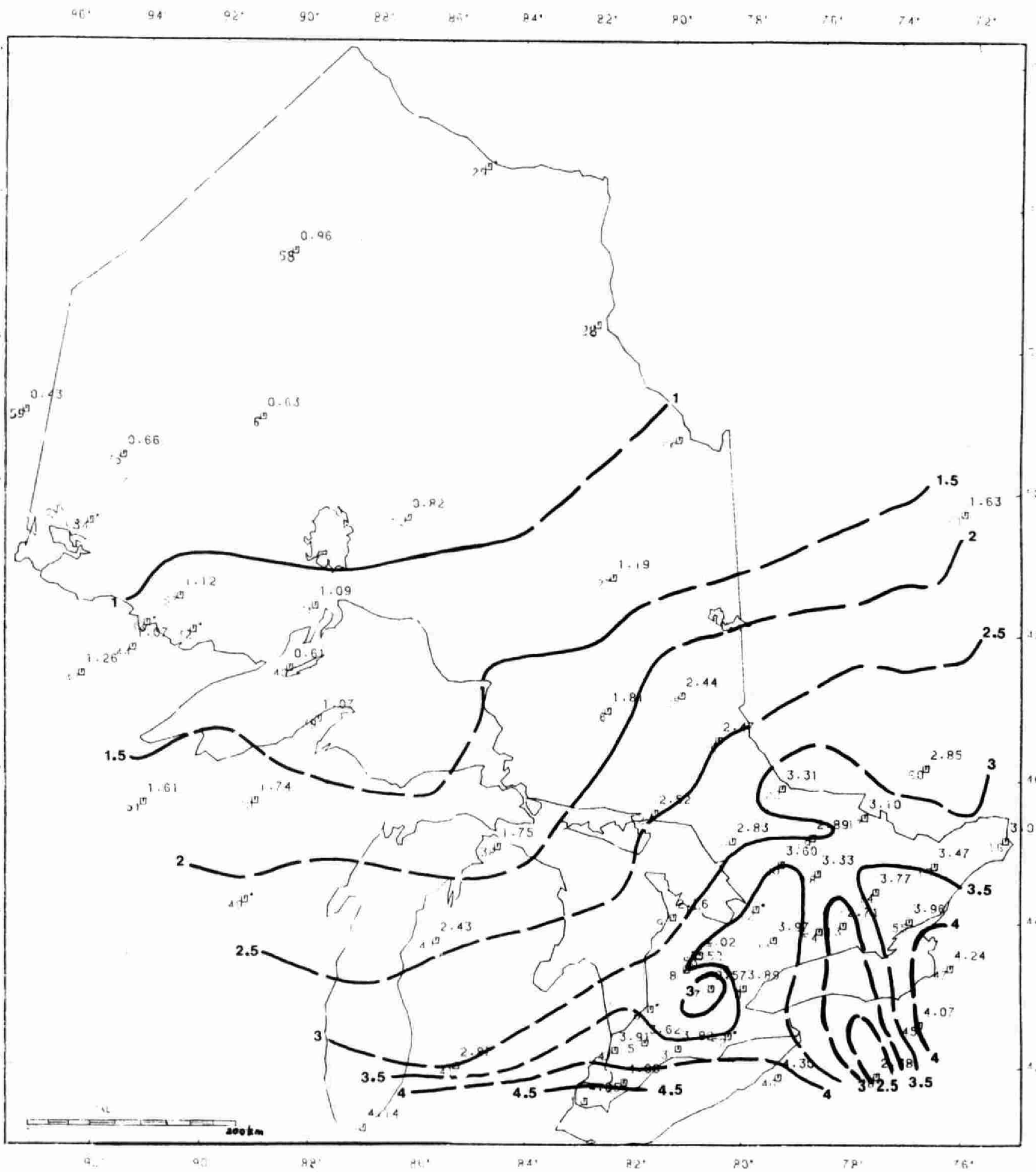

Figure 4: ANNUAL DEPOSITION(G/M**2) OF SO4 - 1981

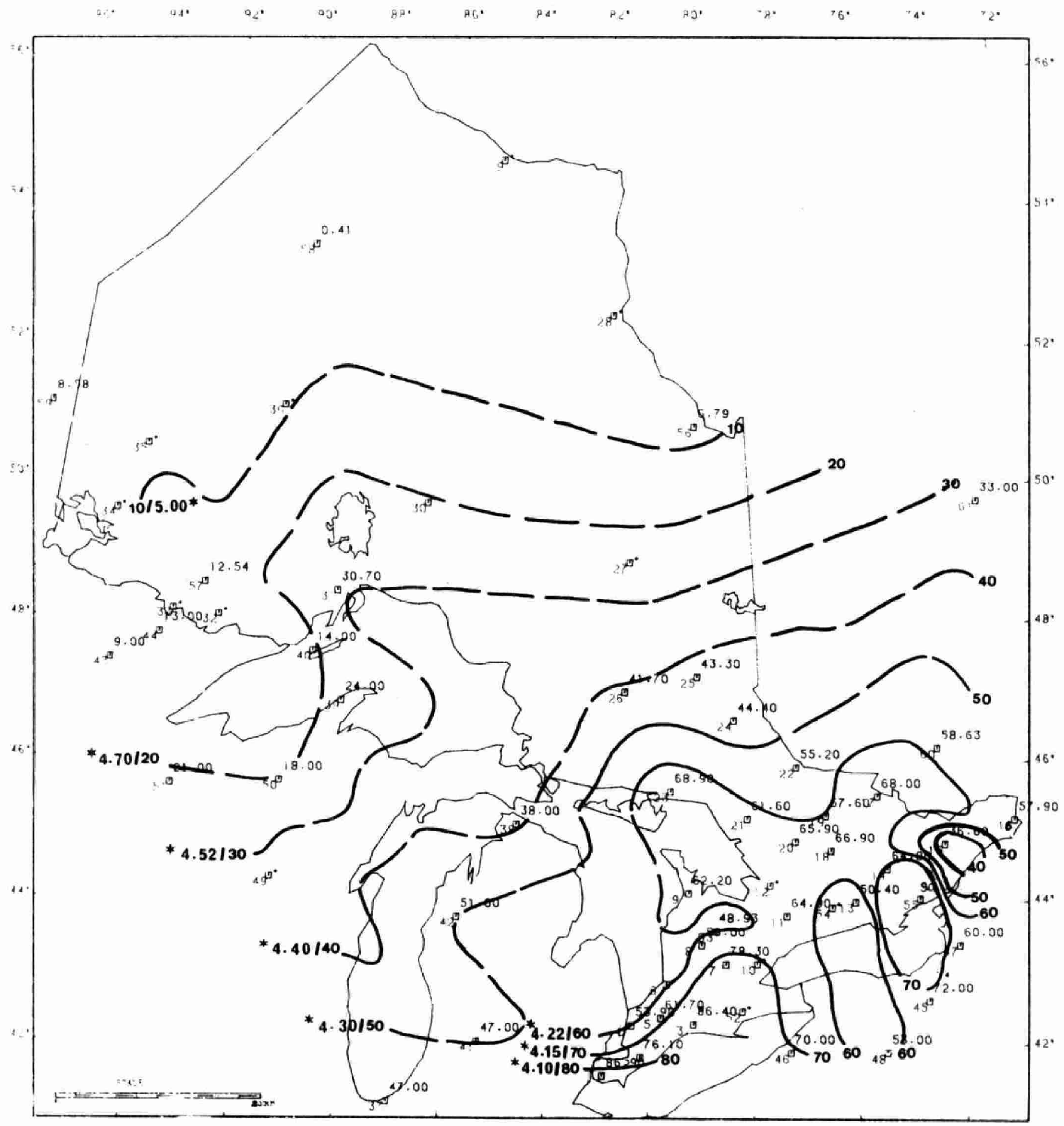

Figure 5: AVERAGED ANNUAL CONCENTRATON (UG/L) OF H_f - 1981

* pH VALUES

TASK #2 - AQUATIC EFFECTS STUDIES

A. Limnology Studies

i) Lake and Stream Chemistry Models

As with the atmospheric models, the development of water chemistry models for lakes and streams is vital as a means of assessing our understanding of the acidification of the aquatic environment. This is important since it provides a tool for predicting either the effects of abatement measures, or the further deterioration of impacted aquatic systems should abatement measures be delayed.

A good understanding of aquatic systems is also important in making an assessment of the size of Ontario's aquatic resource at risk due to acidification. Because Ontario has such a large number of lakes, it is not possible to conduct intensive monitoring studies on any more than a small percentage of them. The development of aquatic models and a documentation of biological effects associated with acidification will provide the basis for extrapolation of this knowledge so that predictions can be made of the effects of acidification on systems not being monitored.

In the development of a model to predict changes in stream chemistry as a function of the deposition of strong acids, a necessary first step is the formulation of a model to predict streamflow. In FY 82/83, a Tennessee Valley Authority (TVA) model was evaluated for application to streams in the Muskoka-Haliburton area. With some modifications to include snowmelt effects, the TVA model had adequate predictive capability in three out of four years' (1976-80) data against which it was tested. A statistical chain-of-lakes model was also developed to predict monthly streamflows. While simpler to operate than the TVA model, it does not permit daily streamflow prediction.

A data base of the watershed and hydrological characteristics of the Dorset calibrated watersheds was compiled. This will provide the requisite information for a model to predict the loss of chemicals from watersheds in general. The loss of total phosphorus as a function of watershed characteristics has already been successfully modelled under the Lakeshore Capacity Study, and a similar approach is being used to study the loss of other chemicals, such as calcium and alkalinity.

Another model being formulated will predict the lake concentration of alkalinity, pH, base cations, and some metals in response to strong acid deposition. A preliminary version of the model applied to four lakes near Sudbury successfully predicted alkalinity changes in two of them. The acid neutralizing capacity of the sediments, which is not taken into account in this version of the model, was probably the reason that the model was unsuccessful in the other two lakes.

ii) Biological Studies

Experiments on the survival of eggs and larvae of three amphibian species, the American toad, the wood frog, and the spotted salamander, were conducted by placing eggs in six streams with varying levels of pH, aluminum, and organic carbon. Strong negative correlations between egg survival and pH and various aluminum species were observed.

In a second experiment, spring snowmelt conditions in a stream were simulated by acidifying it from pH 5.8 to 4.8 for four days and then to pH 4.2 for four days. Significant mortalities associated with pH and aluminum were observed, indicating that short-term pH depression and high aluminum levels that frequently accompany spring snow melt can reduce the hatching success of amphibians. The American toad and the spotted salamander larvae were more sensitive than those of the wood frog.

However, no evidence of pH stress was uncovered in an amphibian survey conducted on a transect line southwest of Sudbury. In a study under contract to MNR, most of the frog and toad species expected in the Sudbury area were found to be common and widespread. A similar survey on a transect line to the northeast of the town will be conducted during 1983.

So little data exist for certain biological communities that impacts of acidification cannot be estimated. In 1982-83 we completed comparative site surveys on three of these communities to assess potential impacts of acidification of community members. The three communities studied were aquatic macrophytes (large water plants), planktonic rotifers and larvae of the phantom midge Chaoborus.

Macrophyte surveys were conducted in 46 lakes near Dorset, Parry Sound, Killarney and Sudbury. Communities of trace metal contaminated lakes near Sudbury had extremely low diversity in comparison with all other lakes, and unique species associations. In the acidic Killarney lakes community richness was not apparently reduced, indicating that the other primary producers in lakes (phytoplankton and benthic algae) respond to depressed pH more rapidly than macrophytes. A comparison of macrophyte biomass in two more intensively studied non-acidic Dorset lakes with one acidic Sudbury lake indicated macrophyte biomass might actually increase in acidified lakes.

Sphagnum invasions have been reported for acidified lakes in other countries. Even though an intensive survey indicated Sphagnum "propagules" probably enter all the lakes, there was no evidence from the intensive survey that Sphagnum was restricted to acidic lakes or was growing at problem densities in them.

Planktonic rotifers were compared in six non-acidic Dorset lakes and two acidified lakes in the Sudbury area. The rotifers were an order of magnitude more abundant in the acidic lakes where they formed 16 to 50 of the total zooplankton biomass in comparison with two in the non-acidic lakes. This increased biomass might follow a decrease in abundance of crustacean competitors - a direct result of acidification.

Recently Scandinavian workers have suggested that densities of the phantom midge Chaoborus, the only insect in the plankton of lakes, should increase in acidic lakes because of the elimination of fish. Because of this hypothesis, Chaoborus abundance in the eight Dorset lakes and in 25 other lakes ranging in pH from 4.5 to 7.4 was measured. The five lakes with lowest pH had no fish. The studies indicated that neither pH nor presence of fish are prime determinants of total Chaoborus abundance in Shield lakes. However, positive correlations between nutrient levels and Chaoborus abundance indicated that if acidification removes fish from mesotrophic lakes, Chaoborus numbers might increase.

iii) Aluminum Studies

Research such as the amphibian experiments described above, the laboratory and field fish toxicity tests described in the next section, and work being conducted by cooperative MNR/MOE experiments on lake trout, walleye, and rainbow trout survival all support a crucial finding: hydrogen ion and aluminum concentrations are key chemical factors linking acidic deposition and biological effects.

One fact emerging from the research is that aluminum toxicity is dependent on what form the aluminum has in solution. The chemistry of aluminum in water is quite complex. "Monomeric" aluminum is basically any chemical species that contains a single aluminum atom or ion. Common inorganic monomers are ionized aluminum (Al^{3+}), aluminum hydroxides ($Al(OH)_x$), and aluminum fluorides ($Al Fx$). In addition, there are organic monomers (one aluminum atom with an organic molecule associated with it), inorganic polymers, and organic polymers.

Aluminum toxicity to fish and amphibians is usually associated with the inorganic monomeric forms, so knowing the total aluminum concentration of an aquatic system may not suffice if we want to predict biological effects. If water has a high organic content, much of the aluminum might be tied up in organic complexes, rendering the aluminum relatively less toxic.

A major accomplishment has been the development of methods for estimating the various forms of aluminum in fresh water, and the establishment of a laboratory dedicated to aluminum speciation at Dorset. An interlaboratory comparison among the speciation methods developed by MOE and different methods used at McMaster and Cornell showed that all of the methods produced comparable results.

During FY 82/83, over 500 water samples from the Muskoka-Haliburton area were analyzed for aluminum species, with emphasis being placed on spring snow melt chemistry. One finding was that aluminum fluoride (Al Fx) complexes dominate the inorganic monomeric fraction. In contrast, ionic aluminum (Al^{3+}) is the major species in Scandinavia. The implications of this finding require further work.

In addition, analytical support for several other research programs exploring aluminum toxicity was provided.

Aluminum has also been implicated in decreased reproduction in birds. Swedish scientists have reported that insect-eating birds have reproductive impairment in acidified areas. The hypothetical cause is elevated aluminum levels in their insect prey being passed on to the birds. Studies undertaken by MNR in the vicinity of Killarney Provincial Park revealed aluminum levels in insects of only about 10 to 15% of those reported in the Swedish studies. The MNR study did reveal evidence of reduced bone growth in young eastern kingbirds, correlated to lower pH.

iv) Calibrated Watersheds

The collection of hydrologic and chemical data for 32 calibrated watersheds and eight calibrated lakes continued through FY 82/83. This data base is being accumulated to develop and test the mass balance models as well as to provide a record of long term changes in lake and stream chemistry.

Lake chemistry data from five lakes which have been gathered since 1976 revealed that no measurable changes in pH, alkalinity, sulphate, or calcium have occurred. The three other calibrated lakes (Plastic, Heeney, and Crosson) have been monitored since 1980, but as yet there is insufficient data for trend analysis.

v) Mesoscale Modelling

A mesoscale model is one which can describe or simulate environmental attributes on an intermediate geographical scale, usually on the order of 50 to 200 km. The mesoscale model is a cooperative MNR/MOE study designed to allow mapping of lake chemistry without chemically sampling each lake. Ontario has over 250,000 lakes, and only a little over 4,000 of them have been sampled for water chemistry. One important question that is still unanswered is the magnitude of Ontario's aquatic resource at risk due to acidification. To answer that, rules for predicting the chemistry of lakes given geological and physical information must be developed.

In conjunction with the Ontario Geological Survey (MNR), a physical survey of Algonquin Park's 2,600 lakes, using aerial photography, was completed. Using chemical data

from about 100 lakes sampled prior to 1982, and geochemical data supplied by O.G.S., preliminary relationships between lake chemistry and physical and geochemical characteristics of the lakes were devised.

During FY 82/83, MNR Fisheries Branch sampled about 1,000 lakes in the Algonquin-Parry Sound area. Some of these data, along with results from an O.G.S. geochemical survey to be completed in 1984, will form a broader base for predicting lake chemistry. Once the relationships are formulated, they will be tested using data sets collected in other areas.

vi) MNR Fisheries Program

The synthesis and modelling component of the MNR Fisheries program is designed to develop empirical models necessary for the prediction. The process of synthesis required for model formulation also serves to isolate and identify critical items of information. The design of experiments and data collection can then be modified to address the information needs. In FY 82/83 development of a model of the response of the chemistry and brook trout population of a small shield lake was initiated. Also initiated was an evaluation of the sensitivity of the Ontario lake trout resource.

The MNR/MOE Comparative Lake Study is designed to test the validity of toxicity thresholds obtained from laboratory and field bioassay tests. (See section on Fish Toxicity Studies). Data is collected on lakes which span the toxicity thresholds for pH and aluminum for lake trout, brook trout, smallmouth bass, and walleye. In FY 82/83, eleven lake trout lakes were sampled using standardized fishing methods. In lakes with average pH of 5.2, no lake trout were caught. In two other study lakes, whose average pH's are about 5.2 and 5.5, an analysis of the age structure of the lake trout population indicates persistent recruitment failures. While no significant trends in trout fecundity were observed, abnormal constrictions in the testes of lake trout from the more acidic lakes were noted.

The trend-through-time study is another cooperative MNR/MOE study. Twelve extremely sensitive lakes have been selected for intensive lake chemistry and fisheries monitoring. This information will be used to formulate models of the impact of acidic deposition on fish communities.

An analysis of the population structure of Westward Lake (Algonquin Park) white suckers revealed that successful recruitment has not occurred for the past five years. MNR began experiments in early 1983 to evaluate possible causes of this failure.

B. Taxonomy Studies

i) Filamentous Algae

As lakes acidify, large mats of filamentous algae sometimes occur in the lake shallows. This has been frequently observed in Scandinavia, and occasionally in North American lakes. This study was designed to look at factors that contribute to excessive algae growth and determine extent and variability of algal communities in lakes of varying pH.

FY 82/83 was the second year of shore zone mapping of algal communities in a set of seven lakes covering the pH range of 4.5 to 7.5. An additional thirty-six lakes were also surveyed, but less intensely. So far, many variables that contribute to algae distribution have been identified. These include lake colour, lake size, and the nature of the lake bottom. In addition to algal community size and type, the chemical composition of the algae was found to vary considerably; some contained extremely high metal levels.

Algae communities in lakes whose water chemistry is being manipulated were also monitored. These lakes include those being neutralized by lime addition, and lakes in the Experimental Lakes Area in northwestern Ontario which are being acidified experimentally.

ii) Odour Production

Another change in algae that sometimes accompanies acidification is a population explosion of algae that produces an intensely disagreeable odour. The organism that is responsible appears to be *Chrysochromulina breviturrita*, which was first described by MOE scientists in 1976. Since then, the alga has been found in many areas of northeastern North America, and reports of odour problems have come from Massachusetts and New Hampshire, as well as Ontario.

What is still uncertain is the condition which triggers the "bloom" of *C. breviturrita* associated with odour problems. Interviews with long-time local residents indicate that it is a recent problem, and by all accounts, such a bloom is a very memorable event. FY 82/83 was the second year of investigation on 12 lakes in the Muskoka-Haliburton area, several of which have had odour problems. It is hoped that these limnological studies will isolate the factors contributing to the sporadic blooms.

Complementary research is being conducted under contract at the University of Western Ontario. In FY 82/83, the first successful laboratory cultures of *C. breviturrita* were established and future work will be directed at determining conditions which promote growth.

An analysis of data from over 100 lakes in Ontario has established that this organism is associated with low pH, and can be present in lakes with a pH as low as 4.5. However, odour problems only seem to occur in coloured lakes with pH in the range 5.7 to 6.2.

iii) pH Change and Algal "Fossils" in Lake Sediments

This study is designed to see if the hard remains of certain algae types found in sediments can be used to indicate recent pH changes in freshwater lakes. One approach is to use diatom "skeletons". These are deposited in lake sediments yearly and the age of the sediments can usually be obtained by lead-210 or other dating techniques. Since diatom communities are fairly characteristic of lake pH, it should be possible to construct a lake's pH history through time.

In FY 82/83, surface sediments from 30 Muskoka-Haliburton lakes with pH's ranging from 5.0 to 7.5 were being analyzed for diatom composition. One problem with this approach is that there are literally thousands of diatom species, and the statistics required to relate a given population structure to a particular lake pH will be extremely complex.

A more promising approach is being developed by MOE scientists using the silicate scales of chrysophyte algae, which are also preserved in sediments. There are only about 100 species of chrysophytes (including six that were previously undescribed). The task of associating chrysophyte communities to lake pH should be considerably easier.

C. Ground Water Studies

i) Contribution to Lakes and Streams

This study is an integral part of the calibrated watershed studies, and is designed to assess the quantity and quality of ground water contributions to lakes and streams.

The three watersheds under intensive sampling in FY 82/83 were Dickie, Harp and Plastic Lakes. The chemistry of ground water in the three watersheds was quite different, and some samples had pH less than 6.0.

The low pH is primarily attributable to natural carbonic acid. Harp Lake was the site of an investigation designed to assess the amount of ground water entering the lake.

Isotope studies on groundwater contribution to streams indicate that up to 80% of water in streams during fall storms may be contributed by ground water.

ii) Ground Water Quality Inventory

The extensive survey of ground water acidity, started in 1980, continued during FY 82/83. The area covered this year was between Timmins, North Bay, and Huntsville along the Trans Canada Highway. Samples were taken from shallow domestic wells dug in sand and gravel and were field tested for pH, conductivity, and temperature. All wells with a field pH less than 6.0 had further samples taken for major ion and heavy metal analysis.

Roughly 15% of the samples had pH less than 6.0, but the chemical analysis of the samples revealed that their acidity was due to dissolved carbon dioxide rather than acidic precipitation. Some of the low pH ground waters were quite corrosive, and leached metals from plumbing systems. In several cases, lead and copper concentrations in samples from unflushed plumbing systems exceeded the drinking water objectives.

D. Fish Toxicity Studies

i) Laboratory Studies

An experiment was conducted to determine whether low pH and high aluminum had adverse effects on rainbow trout. It is known from previous lab and field work that high aluminum and low pH can be potentially lethal to fish, but many lakes in Ontario are acid stressed, not acidified. This experiment was designed to look at the physiological response of the trout to sublethal conditions. The preliminary results indicate that aluminum precipitates on fish gills, but that less aluminum deposits at low pH (4.0) than at higher pH (6.1). Surprisingly, the aluminum deposition at pH 4.0 seemed to provide some protection for the fish, since a much higher percentage of trout died at pH 4.0 when no aluminum was present.

Nonetheless, it is apparent that inorganic monomeric aluminum (75 $ug \cdot L^{-1}$) is toxic to fish between pH 6.1 and 4.5. Oxygen uptake is impaired, and sodium and chloride loss is moderate to severe. The result is that the energy reserves of the fish are depleted, so the fish will have little energy remaining for growth, foraging for food, or development of gonads. It is also likely that these weakened fish will be more susceptible to disease.

MNR funded a study at the University of Toronto to examine the effect of low pH on overwintering young-of-the-year smallmouth bass. Results indicate that the rate of weight decline of the exposed fish increases significantly at pH levels less than 4.5 with a consequent shortening in the time to death from starvation.

ii) Field Studies

Brook, rainbow, and lake trout eggs were exposed at seventeen field sites to varying pH and aluminum levels. The data will hopefully provide toxicity thresholds for sensitive early life stages of the trout.

In addition, effects of episodic events such as spring runoff and rain storms were investigated by placing cages containing the three trout species and redbelly dace at five study sites. The role of differing water chemistry on metal accumulation on gills will be examined in detail.

Egg survival of walleye and white sucker was also studied in a combination of field exposures and laboratory experiments. Lethal thresholds for pH and aluminum will be determined for the early life stages of these two species.

MNR continued experiments to evaluate the effect of long-term (over winter) and short-term exposures of early life stages of lake trout, brook trout, lake whitefish, walleye, and rainbow trout to acidic waters. Mortality of lake trout sac fry coincided with the largest period of pH depression and maximum surface runoff. Despite pH levels of 4.5 to 5.0 and peak concentrations of inorganic aluminum of 40 to 50 $ug \cdot L^{-1}$, about 82% of the sac fry survived.

iii) Metal Accumulation in Fish

It has been established that levels of some metals, such as mercury, lead, and cadmium, increase in fish from lakes of lower pH in the Muskoka-Haliburton area. What is not yet clear is exactly what the role of atmospheric deposition is in these observations. Collections were made in the Thunder Bay area, which receives much lower amounts of acidic deposition. If our current hypothesis is correct, much lower mercury concentrations in fish from Thunder Bay lakes should be seen, even though water chemistry will be similar to the Muskoka-Haliburton lakes.

E. Extensive Lake Sampling

This program is carried out in cooperation with the Ministry of Natural Resources, and is designed to delineate the magnitude of Ontario's aquatic resource at risk due to acidification. To the end of FY 82/83, over 4,000 lakes had been sampled throughout the province, with 155 acidified lakes being identified.

The majority of the acidified lakes are in an elliptical area around Sudbury, stretching to the northeast and southwest of the city. However, an increasing number of acidified lakes are being identified in other areas of the province, including Algonquin Park, Muskoka-Haliburton, Renfrew, and Parry Sound. Mostly these acidified lakes are small headwater lakes, but their distance from point sources strongly implicates long range transport as the cause of acidification.

Another result of the extensive lakes survey has been the identification of three acidified lakes in Pukaskwa National Park, in Northwestern Ontario. These are the first acidified lakes found in this region, and they are unique in Ontario since they appear to be being acidified

by a fairly low rate of wet sulphate deposition. Many of the lakes in the park are extremely sensitive, and a careful monitoring program of lakes and streams in the park is continuing.

Another result of this program has been the establishment of an extensive data base of lake water chemistry. This has provided the basis of a study done on plankton in Northeastern Ontario lakes, which shows that lake pH has a strong influence on the structure of the crustacean plankton community. Also in the Northeast, a number of lakes originally sampled during 1974 to 1976 as part of the Sudbury Environmental Study are being resurveyed to provide a temporal comparison of a large number of lakes after seven years.

F. Remedial Methodologies Development

Lake neutralization is at best a temporary measure to delay or reverse the effects of acidification. Experience in Scandinavia and North America shows that it is not possible to add sufficient neutralizing agent (usually limestone) to a lake to protect it for more than three water residence times of the lake. Excess limestone tends to be inactivated by the formation of a relatively inert coating of metal hydroxides, preventing further dissolution.

However, Ontario is pursuing the development of lake neutralization expertise as a method of protecting and rehabilitating lakes. Even under the most optimistic of emission abatement scenarios, the significant reduction of acid inputs into many of Ontario's lakes is several years away. Lake liming may prove to be a feasible interim measure for the protection of important gene pools, or the rehabilitation of significant sport fisheries.

The lake neutralization study is a joint MOE/MNR program being coordinated by a private company, Booth Aquatic Research. During FY 82/83, efforts were focussed on four lakes: Ruth Roy and Bowland, the "acidified lakes"; and Trout and Miskokway, the "endangered lakes". Detailed mapping of Ruth Roy lake resulted in it being dropped as a prime study lake since it was doubtful whether it could support a reproducing population of lake trout, even if neutralized. Detailed surveys of water chemistry on Bowland Lake were conducted and bioassays confirmed that the lake water was toxic to lake trout.

Small scale additions of powdered limestone to enclosures in Bowland Lake confirmed laboratory estimates of the amount of neutralizing agent required, and showed no adverse effects on the resident population of yellow perch. Selection of a very finely powdered limestone as the neutralizing agent was also completed, and arrangements were made to neutralize the lake in August of 1983.

Biological and chemical surveys of Trout and Miskokway Lakes were completed, to characterize the lakes prior to neutralization. Plans are to add lime to one or both of these lakes during the summer of 1984.

MNR has attempted to re-establish viable fish populations in lakes where indigenous stocks have been lost due to acidification. The survival and growth of hatchery-reared fish have been monitored in 60 such lakes, and nine lake trout populations have been successfully re-established. All of the successful plantings have been in lakes with pH 5.0. A reproducing population of planted brook trout has also been observed in a lake near Sudbury with a pH of about 6.0.

G. Laboratory Support

A total of 188,264 tests were performed in support of the studies comprising the A.P.I.O.S. Aquatic Effects Program. Significant improvements in the delay between sampling and analysis were accomplished by the institution of a new procedure for the measurement of acidity, and the acquisition of two graphite furnace atomic absorption spectrophotometers (GFAAS) used for trace metal analysis. One of the GFAAS's is located at the Dorset lab, and is virtually dedicated to aluminum analysis.

Some of the non-routine work done at the Laboratory for Task 2 included experiments for Booth Aquatic Research as part of the Remedial Methodology Development study. These included evaluation of liquid scintillation as a means of measuring calcium binding in sediments, and particle size determinations on various grades of calcite to determine which grade was to be used for liming lakes.

TASK #3 - TERRESTRIAL EFFECTS STUDIES

Acidic precipitation has the potential to cause serious and widespread effects on terrestrial ecosystems in certain areas of the world such as eastern Canada, northeastern U.S.A., southern Sweden and Norway, Germany and Czechoslovakia.

In experiments using simulated acidic precipitation, a number of adverse effects have been produced in soils and vegetation including:

- the leaching of basic minerals and cations such as magnesium and calcium;
- the mobilization of such soil-bound metals as aluminum and iron;
- changes in biological activities such as nitrification;
- damage to the protective surface waxes on leaves;
- leaf lesions;
- accelerated leaching of nutrients and reduced nitrogen fixation;
- reduction in crop yields.

One major problem with many of these experiments is their lack of reproducibility. Using ostensibly similar conditions, different results have been obtained in many experiments performed by various research groups. In particular, experiments on the effects of acidic precipitation on vegetation seem to yield differing results, so there has been considerable emphasis on standardizing experimental procedures.

In many experiments on vegetation, usually little effect is seen until the pH of applied rain falls below 3.0. However, there is some evidence of leaf damage in sensitive plants at rain pH 4.0, a level of acidity exceeded during many rainfalls in Ontario.

It appears that the effect of acid precipitation on agricultural soils will be minimal. Common farming practices such as fertilizing or liming the soil will overwhelm any effect due to acidic precipitation.

Forest soils, on the other hand, are rarely amended, and any effect on forest productivity has potentially large economic effects. Reductions of forest growth in southern Sweden have been reported, as have die-backs of conifers in the Adirondacks and sugar maples in Quebec. Whether these events can be attributed wholly or in part to acid precipitation is still in doubt.

Of particular interest has been a massive die-back of forests in Germany. According to a report released in November, 1982, over 500,000 ha of forests in Germany have been damaged, and indications are that by the end of 1983, one to one and a half million hectares will have been damaged. This massive destruction of forests has been attributed to air pollution and acidic precipitation, but there is still considerable controversy about the mechanism of damage.

In Ontario, an assessment of the terrestrial effects of acidic precipitation has been divided into studies on vegetation and soil.

A. Vegetation Studies

i) Baseline Vegetation Study

The effects of acidic precipitation on foliage chemistry were addressed in FY 80/81 by the establishment of 30 forest sites. These sites were sampled, and chemical analyses were completed in FY 82/83. One concern was the variability of chemical results for a given tree type. To resolve this, a site variability study was instituted in 1981/82 and continued in 1982/83. This variability study consisted of intensive sampling of a given tree species at particular sites to assess the contribution to chemical composition of varying sample time within the growing season, and sampling location both between trees and within the crown. The results indicate that natural variations in foliage chemistry render it unlikely that effects of acid precipitation can be monitored by this type of sampling, unless the threshold of some crucial regulating system is crossed. Hypothetically, trace element concentrations may become elevated through solubilization of metals in the soil. Consequently, this survey has provided a potentially useful data base for detection of such effects.

ii) Lichen and Moss Study

A contract was let in FY 82/83 to explore the use of lichens and mosses as biological monitors of air pollution. Since lichens obtain a significant portion of their nutrients from atmospheric deposition, and they have been used in the past as air quality indicators, their chemical composition may reflect the chemistry of the deposition.

Over 200 lichen samples were collected across the province and submitted for chemical analysis during FY 82/83. Intensive lichen and moss surveys were also carried out at the biogeochemical sites.

iii) Experimental Studies with Acid Rain

One advantage of conducting studies in controlled situations is that many of the variables to which plants

in natural environments are subjected can be held constant. This makes the development of dose/response relationships considerably easier.

Experiments were conducted in specially constructed indoor acid rain simulation chambers, several of them using radishes, which are a popular experimental organism because they are easy to grow and have a short life cycle. MOE participated in a cooperative study with several American research bodies to standardize experimental procedures. Hopefully, these comparative experiments will reduce the number of conflicting research reports by eliminating differences in soil type, acid rain "recipe", exposure rate, and other variables.

Another experiment was conducted in which radishes were exposed to acid rain at different rates of application while total dosages were constant. Radish root weight was significantly reduced at a given pH if the application occurred over a longer period.

Also during FY 82/83, birch seedlings were collected from eight areas of the province. The hypothesis being tested is that tree sensitivity to acid rain is influenced by native soil, and by genotypic differences that occur between such widely distributed populations.

Sensitivity of important crops to acid rain is also being assessed. This study involves five of the most common varieties of each of the top field crops (i.e. grain corn, alfalfa, soybean, spring and winter wheat, barley, oats, white bean, rye) as well as top ranking vegetables (i.e. sweet corn, onions, turnips, peas, carrots, cucumber, lettuce, green beans, radish, beets, spinach, parsnip and squash). Plants are exposed to rain of varying pH. Observations recorded include germination success, leaf number, visible injury, and weight of the plants.

Other studies in FY 82/83 have included the effect of acid rain on bacterial speck (the disease was inhibited by acid rain). The synergistic effects of acid rain in combination with O_3 (ozone) and SO_2 on peanut plants were also studied. Treatment with acid rain at pH 3.0 and O_3 resulted in more injury than O_3 alone. On the other hand, SO_2 injury was reduced by acid rain treatment. O_3 and SO_2 in combination produced less damage than each gas individually.

The design of the exclusion canopy was completed with the help of Ministry of Government Services. This is basically a greenhouse that can be automatically moved to cover experimental plots during a rainfall. A number of nozzles can apply rain of varying pH at an amount and rate equal to that being detected outside. Other features include pressurized air pipes between the experimental plots blowing purified air to reduce the effects of dry deposition. It is anticipated that construction will be completed in FY 83/84 so that experiments can start in the 1984 growing season.

B. Soils Studies

i) Baseline Soil Study

There is a large amount of data on soils in Ontario, but little of it can be used to assess the sensitivity of soils to acidic precipitation. Most of the data available is on agricultural soils which have been modified by fertilizer application and are no longer representative of the native soil. Another problem is that past analyses of soil have been conducted using a variety of sampling and analytical techniques that are not always comparable to contemporary methods.

The purpose of the soil baseline study was to provide a data base of soil tests across Ontario, using a standardized battery of analyses. This will provide the basis for further resampling of the sites to see if changes in soil chemistry can be attributed to acidic precipitation. They will also permit mapping of Ontario soils according to various soil sensitivity criteria.

The baseline soil sampling is now completed. Since 1980, 3400 samples from 400 sites around Ontario have been collected, and over 88,000 analyses have been performed. Data tabulation is underway, and a report compiling the information should be complete in FY 83/84. Computerized data base formation and initial mapping should be complete in FY 84/85.

As with vegetation, the ability to use chemical analyses of soil to determine the effects of acidic precipitation is limited by the chemical variability of the soil. A soil variability study is being conducted to examine the spatial and seasonal variation of soil characteristics, at the two southern Ontario biogeochemical sites. The results of this study will be crucial in differentiating between changes in soil chemistry which are due to natural variation, and changes which might be attributable to acidic precipitation.

ii) Soil Column Experiments

Two experiments are being conducted on soil columns. The first uses three soil types, each of which is divided into horizons and combinations of horizons. Simulated acid rain at pH 5.6, 4.2, and 3.0 is being applied at 500 ml per week, slightly more than the natural rate in southern Ontario. The water passing through the columns is analyzed monthly for a number of parameters.

This experiment has been running for over 60 weeks, and some very interesting results are emerging. In two of the soil types (Podzol and Brunisol), the pH of the soil leachate has dropped from near neutrality to as low as pH 3.5 (the original soil pH was in the 4.0 to 5.0 range). Apparently, the readily available basic cations have now been leached from the soil, and hydrogen ions are passing through the columns. Also, the Brunisol column with three

horizons began losing aluminum at the rate of 17 $mg \cdot L^{-1}$ after 30 weeks. This is particularly interesting because one of the theories on damage to tree roots requires only 1 $mg \cdot L^{-1}$ of aluminum. This experiment will continue, and a similar one is being set up in the northwest region.

The second experiment on soil columns involves the reconstruction of three soil profiles, representing sand, clay, and silt soil textures. These columns have been exchanged among the northeast, northwest, and southern regions of Ontario, and have been "planted" at various sites. The plan is to dig them up in five years, and look for alterations due to natural exposure to varying levels of acidic precipitation.

iii) Soil Buffering

One measure of the sensitivity of a soil to acidification is to assess its buffering capacity. Buffering capacity is essentially a measure of the resistance a substance or solution has to a change in pH. In FY 82/83, the buffering capacity of 50 organic surface soils was assessed.

All surface soils showed the ability to buffer low and moderate additions of acid. At higher acid additions the surface horizons of clay soils (or Luvisols) became only slightly acidic. Sandy soils that are naturally moderately acidic (Brunisols) had pH drops of 1.0 to 1.5 in their surface horizons. The organic portion of Podzols, which is naturally quite acidic, showed the least change in pH.

The type of acid added affected the results. In general, larger pH drops were observed when nitric acid was added, and smaller changes occurred when sulphuric acid was used. It should be noted, however, that these experiments used much higher amounts of acid than those found in precipitation in Ontario. Most of the surface soils showed a capacity to buffer acid equivalent to 25 years of deposition at current rates.

C. Biogeochemical Studies

The purpose of the biogeochemical studies is to measure the input, export, and internal cycling of nutrients and metals. The calibrated watershed studies under Task 2 are designed to construct nutrient and metal budgets for lakes and streams; the biogeochemical studies extend these budgets to the terrestrial watershed.

FY 82/83 was a year of considerable progress for this study. It marked the first full year of sampling at the southern sites at Harp and Plastic Lakes in the Muskoka-Haliburton region. Two northern sites were also selected, and weir construction was completed. The northwestern site is at Hawkeye Lake, north of Thunder Bay, and the northeastern site is High Falls, west of Sudbury. Both sites are complete watersheds of small streams, and have many similar features.

At each of the sites, watershed mapping and forest inventories are done. The aqueous output of the watershed is measured by chemical sampling of the stream, and a calibrated weir. Deposition monitoring is done by sampling from a platform above the forest canopy. Soil is mapped and analyzed, and water flowing through the soils is collected by lysimeters.

Lysimeters are porous ceramic discs, sealed with plastic on all but one face. A tube is imbedded in the plastic so that liquid may be drawn through the disc. One problem with lysimeters is that a small vacuum is needed to draw soil water through the disc and into the tubes. A major innovation was developed by the contractors at the Dorset biogeochemical site (University of Toronto Forestry), which facilitates the use of lysimeters in the field. A large tank is evacuated periodically with a portable vacuum pump, and connected via valves, tubes, and manifolds to the lysimeters. This permits the unattended collection of soil leachate samples in the field.

Other components of the biogeochemical study sampling scheme are throughfall, stemflow, and litterfall samples. Preliminary results from the Dorset sites show that vegetation can significantly alter the chemistry of precipitation. For example, the pH of throughfall is raised by deciduous trees, and decreased by coniferous trees (throughfall is rain that contacts the forest canopy). Stemflow, which is rain that flows down tree trunks, is also altered significantly. Hemlock stemflow can be as low as pH 3.0, while deciduous stemflow is frequently as high as pH 6.0.

Litterfall is simply the leaves, twigs, seeds, and other organic debris that fall from trees to the forest floor. Chemical analysis of litterfall will give a measure of nutrient input to the forest floor not associated with meteorological deposition. Future investigation will document element storage in the biomass and soil.

In combination, these measurements will be used to construct a model which will describe how deposition chemistry is altered in the terrestrial ecosystem before it enters lakes and streams as surface runoff or groundwater. In addition, the internal cycling pathways for the forested ecosystems will be quantified. Because sampling and analytical methods are uniform at all the sites, it is hoped that differences attributable to precipitation chemistry can be isolated.

D. Laboratory Support

A total of 116,775 analyses were performed in support of Task 3 activities in FY 82/83. Several new methods were developed, including procedures for measuring plant-available phosphorus and aluminum, and for sulphate in soil extracts by ion chromatography. Checks for contamination on lysimeters, stemflow collectors and

sample filters revealed contamination problems on the lysimeters. This could be alleviated somewhat by acid washing. Arrangements were made to transfer some of the analytical load generated by the Dorset biogeochemical sites to the field lab in Dorset.

TASK #4 - SOCIOECONOMIC INVESTIGATIONS

Economics plays a pivotal role in the A.P.I.O.S. program since it provides the basis for policy formulation and evaluation through the determination of the costs and benefits of various options for emissions control. The results of physical scientific research will determine the tolerable deposition limits or thresholds for these pollutants, while an analysis of the control technologies and their costs will determine the level of emission control which can in fact be achieved. In practice, a solution that combines both economics and science is required by evaluating the costs and benefits of various control options.

Some difficulties are inherent in undertaking a cost-benefit approach to the acid rain issue. The private costs of controls and abatement efforts are usually more visible and are generally concentrated on particular industrial sectors or firms. Conversely, the public benefits attributable to pollution abatement investments are often hard to discern since they are widely dispersed over many individuals or regions. The costs of installing pollution control equipment are fairly straightforward to assess, while the damages side of the function is not as easy to determine since the costs of the adverse effects of acid precipitation are difficult to determine quantitatively. There are a number of important difficulties and limitations involved in estimating the quantitative effects of acid rain and the values associated with them.

A. Damages and Benefits Studies

Damages are the adverse effects of waste emissions and environmental disruptions when they adversely affect humans directly or human activities or environmental resources that people hold to be important. Environmental damages, as in the case of acid rain, are often borne by those who are otherwise unconnected with the sources of the polluting materials. Moreover, those who cause pollution effects often bear none of the adverse effects associated with them nor do they compensate those who are affected.

Benefits are the results of actions taken to reduce or eliminate pollution or to prevent environmental disruptions.

Damages and benefits studies are being undertaken in order to develop methods for estimating the biophysical effects of acidic precipitation and to determine their social importance and economic value. Therefore, information is required in several areas including:

- dose/response relationships from changes in pollution levels;

- an inventory of resources at risk;
- human responses;
- monetary valuations of damages and benefits.

Several socioeconomic studies have been undertaken in the province to identify damages due to acid rain and to estimate benefits of its control. Some valuable information has been acquired from the results of these studies to date.

A survey of residents and tourists was undertaken in both recreational and urban areas to ascertain the value and importance they place on environmental resources affected by acid rain. The pattern of responses indicated a strong concern about pollution. Pollution was seen as a major and immediate problem by most people sampled. They indicated that immediate action should be taken to deal with pollution, even if it means some sacrifice of income for Ontario residents.

Respondents were issued an Environmental Quality Ladder to determine the amounts people were willing to pay to prevent varying degrees of environmental degradation. The specific amounts indicated by those willing to pay varied considerably, but were highly correlated with education and income. Interestingly, there was little variation among the three major subgroups in the sample: urban residents, Cottage Country residents and U.S.A. visitors.

The results of this survey also indicate that this measure is a valuable tool for gauging public attitudes and estimating the value of many types of environmental amenities.

In addition to the Amenity Value Survey undertaken, models have been developed to analyse the biophysical and economic consequences of the effects of acid rain on aquatic-based recreation and tourism as well as on the terrestrial and aquatic resource sectors.

These computational procedures can be most usefully applied to test a variety of different assumptions and possible relationships.

These studies have also shown where more information is required to improve the models and to enhance their use for policy analysis. In particular, more generalized dose-response relationships among acid loadings, acidification of lakes, fish production, recreational fishing and agricultural crops should be developed. As a result, some modifications to the scientific program may be required to produce this information.

The benefits of reducing ozone, another pollutant that is produced by atmospheric processes, were also studied by an MOE work group.

Results from the study included the following:

- Ontario's ambient air quality criterion of 80 ppb/hr for ozone is being exceeded on numerous occasions each summer, mainly as a result of imported ozone and ozone precursors from the United States;

- Average annual monetary losses for Ontario food crops are in the range of 15 million dollars, based on possible production increases which would occur as a result of reduced ozone levels. Such losses could range as high as 23 million dollars. (These estimates are based on 1980 dollars.)

This study has been completed and is being used in the development of an oxidants strategy in Ontario.

B. Costs of Abatement and Mitigation

The primary objective of this component is to determine the costs and other economic consequences of SO_2 and NO_x abatement programs and mitigative actions to protect against the adverse effects of acidification.

During FY 82/83, the majority of work in this area was focussed on preparing the final report by the Ontario/ Canada Task Force which was established in 1980 to undertake "A Study and Evaluation of Air Pollution Abatement Options for Inco Ltd. and Falconbridge Nickel Mines Ltd. in the Regional Municipality of Sudbury".

The final report which was released in December 1982 provides a review of the current production processes at both smelters, an assessment of various control technologies, the implications of world metal markets for both Companies and the social and economic implications of the various technologies.

Due to the current poor state of metal markets, it was acknowledged that it might be several years before either Company would be able to finance a major abatement program. Therefore, the Task Force considered that phased reductions of emissions would likely constitute the most practical, effective and equitable way to proceed, with consideration given to traditional forms of assistance to fund the reductions.

In addition, data continued to be compiled for the Ontario Hydro thermal power plants, the Algoma Steel plant at Wawa, the petrochemical refineries in Southern Ontario and mobile source emissions. Control costs were investigated as well. These cost data for industries affected in both Ontario and the U.S. are important for input into the 'screening model' which is described in Task 4C.

C. Development of an Abatement Strategy

The primary objective in this area is to develop computational procedures and methods to help specify and evaluate policies and strategies to deal with the acid rain issue.

During FY 82/83, emphasis was placed on evaluation of control programs and studies with specific reference to the development of an eastern Canadian abatement strategy. In that context, investigations and studies were focussed on two principal areas.

The first topic dealt with determining the level of emission reduction that must be undertaken by Canada and the United States in total and by individual sources in each country to achieve specified deposition objectives in sensitive areas. There are numerous criteria that could be used to allocate emission reductions among SO_2 emitters. For this reason, an analytical procedure, called the screening model, was developed to identify or "screen out" those strategies which are both efficient in terms of minimizing control costs and effective in terms of achieving the desired deposition objectives.

Throughout FY 82/83, the screening model was used to develop and analyse control scenarios for the U.S. and Canada in ongoing negotiations with the other provinces and the federal government.

The second area of focus addressed the policies or legal instruments which could be used to induce SO_2 polluters to implement control measures to achieve the necessary emissions reduction and acid deposition objectives that have been agreed upon. An Intergovernmental Work Group has been established to study the implications of various implementation policy options that could be employed to strengthen existing laws and programs. Policies being studied include emission charge schemes, tradeable emission permits and financial assistance.

TASK #5 - LEGAL INITIATIVES

A. Provincial Initiatives

Ontario considered Canada's commitment under the Memorandum of Intent to be a serious one and, as a result, has imposed new and tougher Regulations on its two major sources - Inco Limited and Ontario Hydro. These two sources account for 70% of the province's total emissions.

In August of 1980, Inco was issued a Regulation to reduce its SO_2 emissions from 3,266 metric tons per day to 2,260 metric tons per day from its Copper Cliff Smelter effective immediately. Furthermore, by January 1983, SO_2 emissions were to be reduced down to 1,769 metric tons per working day. Inco has met the requirements of this Regulation through the installation of a new milling process which rejects more of the sulphur in the ore before it reaches the smelter.

The current government Regulation on Ontario Hydro limits its SO_2 emissions to 260,000 metric tons by 1990, a reduction of approximately 43 percent from an average of 1980, 1981 and 1982 levels.

Throughout FY 82/83, staff were involved in a continuous assessment of the effectiveness of the various legal instruments available and an investigation of alternative economic and legal mechanisms to induce compliance.

B. International Initiatives

Ontario has repeatedly been concerned that, in spite of the fact that under the Memorandum of Intent both Canada and the United States agreed to enforce existing laws and regulations in a way which is responsive to the problems of transboundary air pollution, the United States Environmental Protection Agency continues to propose revisions in State Implementation Plans (S.I.P.) which would lead to increases in allowable sulphur dioxide emissions from coal-fired power plants.

Therefore, Ontario has undertaken to participate in any U.S. proceedings which could affect, as a result of long range transport, the province's environmental quality. Ontario's efforts have been directed at encouraging the U.S. E.P.A. Administrator to disapprove any S.I.P. revisions which would result in any increase in permissible emissions of SO_2 in the U.S.

Throughout FY 82/83, Ontario specifically intervened in two cases where a coal-fired power plant had requested a revision to its S.I.P.

On June 20, 1982, the Province of Ontario intervened at a Public Hearing of the Michigan Air Pollution Control Commission in opposition to the request by Detroit Edison for delaying the compliance date for its Monroe Power Plant to meet the Michigan "one percent or equivalent sulphur in fuel rule" from 1985 to 1990.

Ontario argued that the SO_2 emissions from the Monroe Plant could not be considered in isolation since they contribute to the aggregate of emissions in northeastern North America which are a cause of adverse effects on sensitive ecosystems; that granting the request would be in violation of the spirit of the Memorandum of Intent in which Canada and the United States agreed "to promote vigorous enforcement of existing laws and regulations"; and that the company had overestimated the costs of compliance and underestimated the benefits of control.

Ontario again appeared at the July 20, 1982 Commission meeting where this matter was voted on. At that time, the Commission decided not to grant the request. At its November 29, 1982 meeting, the Commission considered a 1.9% sulphur in fuel limit for Monroe. Again, Ontario submitted a statement to the Commission recommending compliance with the 1% sulphur in fuel rule. The Commission ultimately rejected the 1.9% option as well. Detroit Edison immediately challenged the Commission's decision in court but subsequently dropped the suit. Every indication is that the Company intends to meet the compliance date through coal blending.

The second intervention in U.S. S.I.P. proceedings by the Province occurred in February 1983 when Ontario submitted a letter to the Indiana Air Pollution Control Board in opposition to the proposed sulphur dioxide emissions limit increase from 6.0 lbs of SO_2 per million BTU of heat input to 7.11 lbs for the Indianapolis Power and Light Generating Station in the Pike County Air Quality Basin. In spite of the objections raised by Ontario and other agencies, the Board approved the Company's request. However, since all S.I.P. revisions must ultimately be approved by the U.S. federal Environmental Protection Agency, Ontario is waiting for the revision to be submitted to the E.P.A. at which time it will again protest the relaxation of this S.I.P.

The 1981 decision of the Air Pollution Control Board of the State of Indiana which approved the request from the Indiana-Kentucky Clifty Creek Generating Station for an increase from 6.0 to 7.52 lbs per million BTU was submitted to E.P.A. during 1982. Since Ontario had opposed this increase at the state level, arrangements were made for the purposes of considering expressing Ontario's opposition. No notification of a public comment period has been received to date from E.P.A.

Representatives of the Ontario Ministry of the Environment presented technical evidence on transboundary air pollution to a Hearing Panel of the United States Environmental Protection Agency in Washington D.C., on June 19, 1981. Ontario's presentation offered evidence relevant to petitions by New York and Pennsylvania that emissions from the Midwest States were impacting on their environments. The E.P.A. has not yet reached a decision with respect to these petitions. Ontario has continued to offer its support to the petitioning States.

Until June 1982, Canada and the United States were still negotiating under the Memorandum of Intent of 1980. At this time, Canada offered to reduce its SO_2 emissions by 50% contingent upon similar U.S. actions. Unfortunately, official negotiations broke off and were never resumed.

As a result, Ontario has continued in its investigations of the feasibility of petitioning the U.S. Environmental Protection Agency under Section 115 of the U.S. Clean Air Act which deals with international pollution. This legal avenue has been under consideration since January 13, 1981, when Douglas M. Costle, former Administrator of E.P.A., declared that U.S. emissions were negatively affecting Canada's environment and that the provisions of Section 115 of the U.S. Clean Air Act should apply to Canada. Ontario has always contended that Mr. Costle had activated Section 115 by this statement and therefore, that the E.P.A. must take the Canadian environment into account in setting limits on U.S. emissions. However, the new E.P.A. Administration has denied any activation of Section 115 by Costle. Therefore, legal action by Ontario under this Section is still a viable option if negotiations do not resume and no control action is announced by the E.P.A.

TASK #6 - PUBLIC RELATIONS INITIATIVES

A. Provincial Initiatives

Throughout FY 82/83, public relations activities focussed largely on Ontario in an effort to inform the Ontario public of all elements of Ontario's acid rain program and to generate continued public support for the program.

The successful response to previous Open Houses at Dorset and the Kortright Conservation Area prompted two additional events in the summer of 1982. These were held in the Parry Sound and Sundridge areas to provide cottagers and local residents further north with a similar opportunity to communicate with scientists about the acid rain problem in general and also its relevance to specific local concerns.

Several fact sheets were prepared throughout the year to provide background information for events such as the Open Houses and to respond to general requests for information from the public.

During the year, an update to the Ministry brochure "The Case Against the Rain" was completed, incorporating information on Ontario's interventions in the U.S. and the Ontario Hydro Regulation.

Also, within Ontario, educational materials on acid rain were provided to the school systems. The acid rain component of the "Environmental Explorations" material supplied to schools combined with visits to 182 schools/ educational locations contributed to this continuing educational program on acid rain. In addition, acid rain was a principal subject of more than 150 workshops and seminars staged by the Exploration Crews at parks, community centres and similar locations during the summer.

Requests for information from students, teachers and the concerned public are constantly handled by many Ministry Branches involved in the acid rain program.

For example, the continuing stream of calls from actual and potential cottage owners requesting information about the sensitivity of particular lakes served as an indicator of interest and knowledge in this sector of the Ontario public. It is apparent that there is widespread and deep concern about the acid precipitation problem in the province and the Ministry has satisfied more than 6,000 requests for specific information on lake sensitivity since the survey results became available in 1981. Approximately 10,000 sensitivity fact sheets are distributed per year.

B. United States Initiatives

During FY 82/83, the major emphasis of the Ministry's A.P.I.O.S. communications program was to continue the activities aimed at informing the American public of the nature and environmental consequences of the acid rain problem in order to encourage support for abatement actions in the United States.

The American campaign included a tour of the research facilities at Dorset for senior American journalists of leading publications as well as field trips and scientific briefings. This tour resulted in increased coverage of the acid rain issue by U.S. media, specifically a cover story in Time magazine, major coverage in the Christian Science Monitor, a series in U.S.A. Today and three articles in the Washington Post.

These major stories and many subsidiary items in the American media helped to stimulate and shape public and political opinion. A combination of this extensive media coverage, continuing pressure for action from various American environmental groups, several Bills on acid rain being considered by the U.S. Congress and the increased documentation of research results in North America, resulted in the issue moving from relative obscurity in 1981 to a fairly high public profile at the end of calendar 1983.

C. Conference Participation

Ontario has responded to numerous requests (see Table II for a list of Conferences) from various international agencies for speakers on the acid rain problem. This demand illustrates the high profile of the issue as well as the high calibre of Ontario's research program.

From a scientific or academic perspective, the benefits of having Ontario scientists participate at these expert meetings include:

- continued program information exchange which can ultimately improve Ontario's research program;
- the establishment of new contacts for further information exchange;
- enhancement of the profile of Ontario's program;
- access to 'free consultation services' during informal discussions;
- opportunities to keep abreast of the most recent scientific developments.

In addition to these scientific benefits, participation by A.P.I.O.S. staff at international conferences, workshops, seminars and meetings continues to highlight the issue in general and Ontario's position in particular. The amount of interest generated by Ontario's appearance in such fora is unlimited and often results in additional media coverage for the province's acid rain program. At a time when public support is needed to convince the U.S. Administration of a commitment to abatement action, it is important to keep the acid rain issue in the public's eye at all levels. Conference activities serve as a valuable tool in this sense as they address multiple audiences.

TABLE II

ONTARIO' S PARTICIPATION IN ACID RAIN EVENTS

FY 82/83

Date	Event
April 7, 1982	APCA Southeast Michigan Chapter Meeting, Detroit, Michigan.
April 12-15, 1982	XIV Air Pollution Workshop, Riverside, California.
April 16, 1982	U.S. NAPAP/RMCC Meeting, Washington, D.C.
April 26 - May 5, 1982	Meeting of the International Standards Organization Working Groups on Air Quality, Cologne, Germany, plus meetings with staff of Umweltbundesamt in Germany.
May 4-6, 1982	International Association for Great Lakes Research 25th Anniversary Conference, Sault St. Marie, Ontario.
June 16, 1982	Annual Meeting of Lime Association, Moncton, N.B.
June 16-18, 1982	Workshop on Simulation Models of Water Acidification, Stockholm, Sweden.
June 20-25, 1982	Stockholm 1982 Conference on Acidification of the Environment, Stockholm, Sweden.
	(N.B. Canadian participation at this conference greatly helped strengthen the final document in view of the U.K. and U.S.A. objections to any significant statements.)
June 20-25, 1982	75th Annual Meeting of the Air Pollution Control Association, New Orleans, Louisiana.
June 28-30, 1982	Ministerial Conference on the Acidification of the Environment, Stockholm, Sweden.
July 8, 1982	Meeting of the Wisconsin Legislative Council's Special Committee on Acid Rain, Madison, Wisconsin.
August 10-12, 1982	Workshop on "Methods for Comparing Precipitation Chemistry Data" sponsored by the Utility Acid Precipitation Program, Rensselaerville, New York.

Date	Event
August 23-28, 1982	XII International Meeting for specialists in Air Pollution Damages and Forests, Oulu, Finland. (August 29-31, 1982, visit to Uppsala, Sweden to view Swedish Coniferous Forest Program.)
August 30 - September 1, 1982	Symposium on the Monitoring and Assessment of Airborne Pollutants with Emphasis on the Long Range Transport and Deposition of Acidic Materials, Ottawa, Ontario.
September 5-13, 1982	Visits to institutes and algologists in Oslo, Gothenberg, Lund.
September 14-17, 1982	SIL Workshop on Periphyton, Växjö, Sweden.
September 19-25, 1982	International Liming Workshop, University of Washington, San Juan Island, Washington.
October 13, 1982	Acid Precipitation and the St. Lawrence Valley - A Canadian-American Conference, Ogdensburg, New York.
October 20-23, 1982	Man-Environment Conference 1982, Hamilton Ontario.
October 25-28, 1982	Symposium on Acid Rain - Soil Conservation Society of America, Burlington, Vermont.
October 28-29, 1982	Colloque sur les précipitations acides, Montréal, Québec.
November 7-10, 1982	APCA - Atmospheric Deposition Specialty Conference, Detroit, Michigan.
November 17-18, 1982	EPA Workshops - Evaluation of Critical Assessment Document: The Acid Deposition Phenomenon and Its Effects, Research Triangle Park, N.C.
November 28 - December 3, 1982	4th International Conference on Precipitation Scavenging, Dry Deposition and Resuspension, Santa Monica, California.
March 22-25, 1983	Sixth Symposium on Atmospheric Turbulence and Diffusion, American Meteorological Society, Boston, Massachusetts.
March 23-24, 1983	Workshop on Institutional Arrangements for Bi-National Air Quality Management, Racine, Wisconsin.

SUMMARY

The Acidic Precipitation in Ontario Study was started in Fiscal Year 1979/1980. The study's mandate is to document the effects of acid precipitation in Ontario and to develop control programs. This Annual Report documents the achievements of the scientists, technicians, economists and lawyers working on the Study, with emphasis on the year 1982/1983. (Budget of $8.77 million.)

Atmospheric Studies

- an accurate inventory of all significant sources of sulphur and nitrogen oxides, both in the United States and Canada, for the year 1980 has been completed.

- continued development of computer models to describe gas emission, transport, chemical transformation, and deposition, with the models being continuously refined.

- an analysis of air parcel movements over an 18 month period showed that over 50% of the sulphate and nitrate loadings in Ontario are associated with air flows from the south and west.

- deposition patterns of hydrogen ion, sulphate, nitrate and other chemical species over Ontario were published. All of southern Ontario receives more than 20 kg/ha·yr of sulphate in wet deposition.

Aquatic Studies

- significant progress was made on a mathematical model which will predict changes in lake water chemistry in response to deposition of strong acids. A preliminary version of the model successfully predicted alkalinity changes in two out of four Sudbury lakes to which it was applied.

- experiments on amphibian eggs showed sharply increased egg mortality with pH drops and aluminum level increases, such as those seen during spring snow melt.

- surveys of plankton communities in lakes covering a wide range of pH's showed significant changes in abundance of some species at different pH's.

- the crucial role of aluminum in the toxicity of low pH water to fish and other aquatic organisms was reaffirmed. Methods which differentiate forms of aluminum in water were refined.

- Ministry of Natural Resources began the development of a model which would describe the response of fish communities to acid deposition.

- attempts to plot historical changes in lake pH using the fossil remains of diatoms and algae in lake sediment were continued.

- toxic thresholds of various pH and aluminum levels to several species of fish during different stages of development were determined in a series of laboratory and field studies.

- updated lists of over 4,000 lakes, including their sensitivity to acidification, were published.

- background data on three lakes prior to neutralizing the lakes with limestone was gathered.

Terrestrial Studies

- a survey of vegetation from a number of sites in Ontario was completed. Chemical analyses should reveal if changes in elemental composition can be attributed to acid deposition.

- several experiments to determine crop yield as a function of various levels of rain acidity were completed.

- design of a new experimental facility to determine crop response to acid rain were completed.

- a survey of soils from a number of sites across Ontario was completed. Results will be used to define areas in Ontario with soils of low buffering capacity.

- columns of different soil types have been leached with solutions of varying pH for many weeks. In some columns, large increases in aluminum export have been observed.

- the first year of complete study at the two southern biogeochemical sites was completed, and the two northern sites were mapped and set up.

Socioeconomic Investigations

- a willingness-to-pay survey of residents and tourists in both recreational and urban areas was undertaken. The pattern of results indicated a strong concern about pollution in general and acid rain in particular.

- models have been developed to analyse the biophysical and economic consequences of acid rain on aquatic-based recreation and tourism as well as on the terrestrial and aquatic resource sectors.

- the final report by the Ontario/Canada Task Force on Abatement Options for Inco Ltd. and Falconbridge Nickel Mines Ltd. was prepared and released.

- control cost data for other industrial sectors in both Canada and the U.S. were compiled.

- the screening model, which was developed to identify optimum control strategies from both the economic and environmental perspectives, was used to develop and analyse control scenarios for the U.S. and Canada.

- the implications of various implementation policy options that could be employed to strengthen existing laws and programs were reviewed.

<u>Legal Initiatives</u>

- the effectiveness of different legal instruments to ensure compliance was assessed.

- an intervention at a Hearing of the Michigan Air Pollution Control Commission in opposition to the request by Detroit Edison to delay the compliance date for its Monroe Power Plant to meet the Michigan "one percent or equivalent sulphur in fuel" rule was successful.

- a letter was submitted to the Indiana Air Pollution Control Board in opposition to the proposed sulphur dioxide emissions limit from 6.0 lbs of SO_2 per million BTU of heat input to 7.11 lbs for the Indianapolis Power and Light Generating Station. Unfortunately the increase was approved at the state level.

- continued monitoring of the status of the Section 126 proceedings which were initiated by the States of New York and Pennsylvania and supported by Ontario.

<u>Public Relations Initiatives</u>

- Open Houses conducted in the Parry Sound and Sundridge areas.

- several fact sheets were prepared to provide background information on Ontario's acid rain program.

- an update to the Ministry brochure "The Case Against the Rain" was completed.

- educational materials on acid rain were provided to the school systems.

- a tour of the research facilities at Dorset was hosted for senior American journalists of leading publications which resulted in increased coverage of the acid rain issue by U.S. media thereby raising its public profile.